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COLOR-IR AERIAL PHOTOS FOR ASSESSMENT OF DIEBACK AND MORTALITY IN NORTHERN HARDWOOD FORESTS

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COLOR-IR AERIAL PHOTOS FOR ASSESSMENT OF DIEBACK AND MORTALITY IN NORTHERN HARDWOOD FORESTS

by

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ABSTRACT

Color infrared (CIR) aerial photographs were evaluated for their ability to resolve hardwood branch dieback and tree mortality in northern hardwood forests. Three sites in central Vermont were photographed at three photo scales; 1:4,000, 1:6,000, and 1:8,000. Damage types detected on the photos are described. Systematic counts of declining and dead trees, at a photo scale of 1:8,000, are an adequate predictor of ground conditions. Areas of decline and mortality in northern hardwoods may involve several tree species and several causal agents.

INTRODUCTION

A number of diebacks and declines of commercial tree species, especially in Eastern North America, have been reported and described. In most cases, a specific casual agent has not been associated with this syndrome. Diebacks and declines are generally believed to be the result of a complex of predisposing, inciting and contributing factors acting in combination. These factors may include diverse casual agents such as drought, root pathogens, defoliating insects, soil compaction, salt, and atmospheric deposition of pollutants (Manion 1981).

One of the more widely publicized forest declines in recent years is a decline of red spruce, Picea rubens, in the Northeastern United States. It has been suggested that atmospheric deposition of pollutants may be a predisposing factor in this decline (Vogelmann 1982; Johnson and Siccama 1983; Siccama et al. 1982). A survey using CIR aerial photography as an intermediate sampling stage was recently completed over a three state area to provide data on the status of this decline (Weiss et al. 1985).

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Another decline which has received recent attention from both the scientific community and the public is a decline of sugar maple, *Acer saccharum*, in the eastern United States and Canada (Westing 1966; Lacasse and Rich 1964; Gagnon et al. 1985; Paradis et al. 1985). This decline has been reported in ornamental and roadside maples, wood lots, and sugar bushes. Atmospheric deposition of pollutants has been suggested as one of a number of predisposing factors (Manion 1981; Gagnon et al. 1985). In 1984, approximately 30,000 acres of hardwood mortality and decline, principally sugar maple, were mapped in Vermont. These areas are believed to be, at least in part, associated with defoliation by forest tent caterpillar, *Malacosoma disstria* Hbn., which occurred at epidemic levels in that state from 1978 to 1982 (Teillon et al. 1985).

A preliminary evaluation was begun in 1984 to determine the feasibility of using medium scale color infrared (CIR) aerial photography as an intermediate sampling stage in a statewide inventory of decline and mortality in northern hardwoods in Vermont. Objectives of this work were to:

1. Identify and describe damage types that are visible on CIR aerial photos either associated with decline or which may be sources of commission error.

2. Evaluate photo counts at several photo scales as predictors of ground conditions.

This work was necessary to recommend aerial photo specifications for a cooperative inventory of hardwood decline and mortality proposed by the Vermont Department of Forests, Parks and Recreation, and USDA, Forest Service, Northeastern Area.

REVIEW OF THE LITERATURE

SYMPTOMS

A number of symptoms of hardwood diebacks and declines are reported in the literature. These include reduced growth, abnormally small, discolored or chlorotic foliage, branch dieback, epicormic branching, root necrosis, and eventual tree mortality (Manion 1981).

Symptoms specifically associated with sugar maple decline include:

1. Smaller, paler foliage which may exhibit marginal necrosis ("scorch").

2. Premature fall coloration and leaf drop.

3. Dieback of terminal twigs and branches, particularly in the upper crown.

4. Reduced growth rates.

5. Root necrosis.

Death may occur after a period of several years or trees may recover (Westing 1966).

AERIAL PHOTOGRAPHY FOR ASSESSMENT OF HARDWOOD DECLINE AND MORTALITY

A limited amount of work has been done to date on detection and assessment of hardwood decline and mortality in North America. A comprehensive review of damage types one would expect to encounter on aerial photos is presented by Murtha (1972). Ulliman and French (1977) were able to achieve 100 percent detection of oak wilt centers caused by the fungus *Ceratocystis fagacearum* (Bretz) Hunt, but had difficulty with commission errors on 1:24,000 CIR aerial photos in northern Minnesota. Croxton (1966) compared 70 mm color photos at two photo scales; 1:1,584 and 1:7,920 to identify ash, *Fraxinus* sp. and classify their decline status in New York. He reported moderate success at the 1:1,584 scale. Photo interpreters working with the smaller scale were unable to identify tree species accurately. Lillesand et al. (1979), developed a model based on microdensitometric analysis of color and CIR aerial photos to predict stress of urban maples in Syracuse and Rochester, New York. Mielke et al. (1984) used 1:6,000 9-inch format CIR aerial photos to inventory decline and mortality associated with a recent discovery of beech bark disease caused by the beech scale, *Cryptococcus fagi* and the fungus, *Nectria coccinea* var. *faginata* in West Virginia. They described the damage types indicative of beech bark disease visible on CIR photos and developed criteria to separate them from other forest damage types which occurred in the survey area.

METHODS

AERIAL PHOTOGRAPHY

Three sites in central Vermont, with known areas of hardwood dieback and mortality, were selected for aerial photography by representatives of the Forest Resource Protection Section, Division of Forestry, Vermont Department of Forests, Parks and Recreation (Table 1). Each site was photographed during August 1984 at three photo scales: 1:4,000; 1:6,000; and 1:8,000 with Kodak Aerochrome infrared film (Type 2443)[2/] in combination with a Wratten 12 (minus blue) and antivignetting filter. Photography was acquired with a Forest Service Beechcraft Queen Air aircraft and a Zeiss RMK 21/23 9-inch aerial camera. A single strip of photos with 70 percent overlap was taken over each target site for each photo scale.

[2/] Mention of commercial products is for convenience only and does not imply endorsement by USDA Forest Service.

PHOTO INTERPRETATION

The stereo triplet closest to the actual target site location which covered a land area common to all three scales of photography was selected from the strips of aerial photos for each photo scale.

The overlap zone of each triplet was examined in stereo with an Old Delft scanning stereoscope. All damage types observed in both hardwoods and conifers were recorded and described. Existing descriptions of forest damage (Murtha 1972) and experience gained from related projects (Mielke et al. 1984; Weiss et al. 1985) were used to aid in classification of damage types. No attempt was made to identify species of either living or dead trees on the aerial photographs.

Table 1 - Summary of target sites included in aerial photo evaluation of hardwood decline and mortality, central Vermont - August 1984

Site[1/]	Decline Condition	Date of Photography
1. Delectable Mountain	Light and scattered	August 18
2. Mt. Carmel	Heavy and scattered	August 21
3. Chittenden	Heavy and concentrated	August 21

[1/] Site names correspond to names of 1:24,000 USGS topographic maps on which the site is located.

Systematic counts of hardwood tree crowns containing dead branches or that were dead or dying were made in stereo on 16 2-1/2 acre grid cells for each site. These were located in the center photo of each location/scale triplet in such a way that each 2-1/2 acre grid cell represented the same area of land at each photo scale. Counts were made by a single photo interpreter. Clear plastic overlays with 2-1/2 acre grid cells calibrated for each photo scale were used to make the photo counts.

DATA ANALYSIS

Onset of autumn coloring of hardwoods by mid-September in the target sites precluded a meaningful assessment of ground conditions prior to the end of the 1984 field season. Therefore, photo counts on each target site were compared with a simulated ground count derived from a capture-recapture statistic described by Maxim et al. (1981). This was accomplished by having a second photo interpreter make an independent photo count of each 2-1/2 acre grid cell on the 1:4,000 scale photos of each site. The location of each dead or declining tree was recorded on a clear plastic overlay. Comparison of this overlay with the results of the initial PI counts from the 1:4,000 scale photos provided a count of the number of trees tallied that was common to both photo interpreters.

An estimate of the population size N (simulated ground count) was obtained by:

$$N = N_1 N_2 / N_{12}$$

where:

N_1&N_2 = photo counts by individual photo interpreters.
N_{12} = photo counts common to both photo interpreters.

N was estimated for each grid cell in this manner. The effect of scale on the relationship between photo counts was described using a linear regression where:

X = the individual grid cell photo counts for each site and photo scale.
Y = individual grid cell simulated ground counts for each site.

The capture-recapture statistic should not be considered a substitute for ground data. This approach assumes that each detection is independent and that there are no false positives (Maxim et al. 1981). In the absence of ground data, we were unable to test these assumptions. This method was used only as a basis for comparing counts at different photo scales and not as an evaluation of an alternative to acquisition of ground data.

GROUND DATA

A ground examination of the Chittenden target site was made by representatives of the Vermont Department of Forests, Parks and Recreation, and the USDA, Forest Service on May 21, 1985. This examination provided data on tree species affected, occurrence of damage types, and insects and diseases associated with the dieback and mortality.

RESULTS AND DISCUSSION

DAMAGE TYPES

A wide range of damage types were identified on the aerial photos and confirmed on the ground (Figure 1). These are described as follows:

EARLY FALL COLORING (II-G)[3/] - The presence of premature fall coloring appears as an orange or yellow-orange hue on CIR film. This is opposed to a distinct yellow color of a dying tree with a red or red-brown foliage color. Trees with premature fall coloring were observed on all three sites. By late August it is possible for individual, apparently healthy trees, especially red maples, *Acer rubrum*, to display early fall coloring. Therefore, in the absence of other symptoms of decline and damage, it is questionable if this symptom by itself is a reliable indicator of hardwood decline on aerial photos.

[3/]Numbers in parenthesis refer to damage types described by Murtha (1972) and Murtha and McLean (1981).

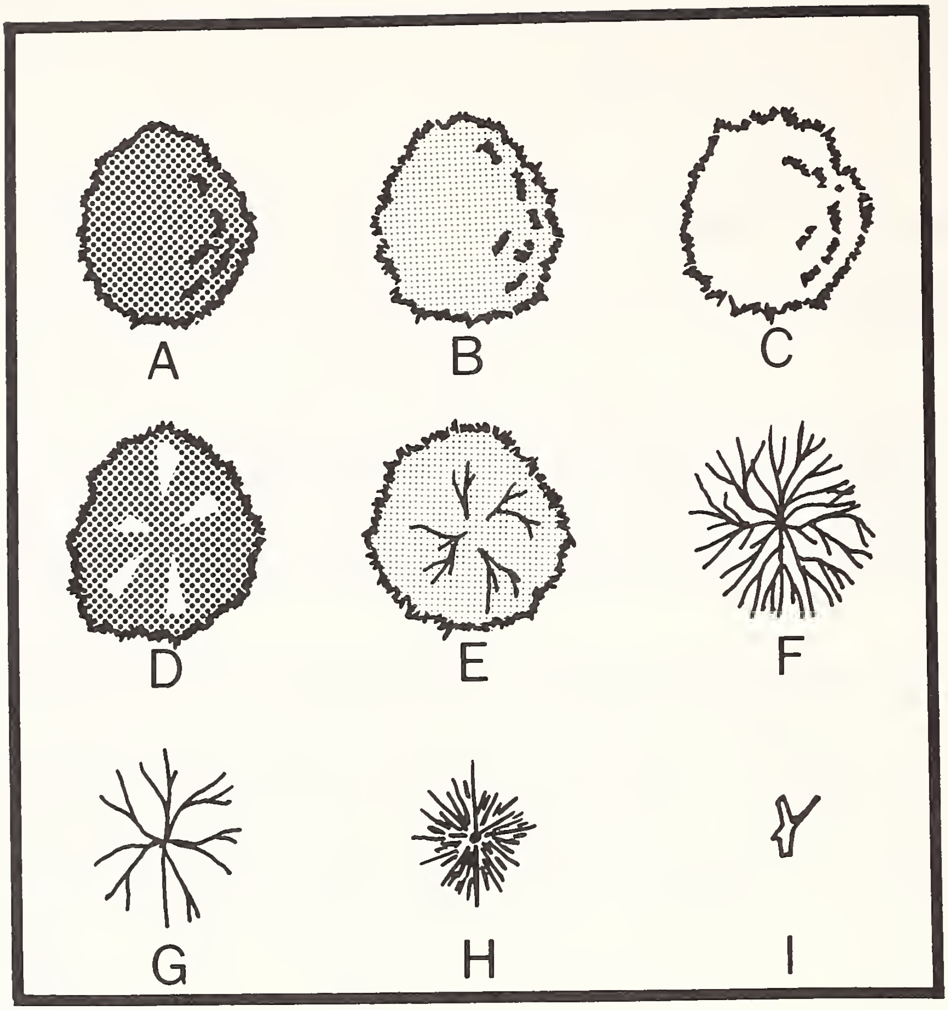

Figure 1 - Examples of forest damage types in central Vermont as they appear on CIR aerial photos.

A - An apparently healthy hardwood with a full compliment of foliage.

B - A slightly chlorotic hardwood. Trees which fall into this category have a full compliment of foliage that is yellow-green in color. On CIR film, these crowns have a distinct pink hue.

C - An acutely chlorotic hardwood. These trees have foliage that is a distinct yellow color. On CIR film they appear white.

D - Hardwood with a full compliment of apparently healthy foliage and "flags" of acutely chlorotic or dying foliage.

E - Hardwood with branch dieback in crown. Color of living foliage may be indicative of an apparently healthy crown, slight chlorosis or early fall coloring (yellow-orange on CIR film). Foliage may also have a thin appearance.

F - Recently dead hardwood; crown has a dendritic network of many fine branches.

G - Older dead hardwood with fewer fine branches.

H - Recently dead conifer with many fine branches radiating from mainstem.

I - Snag with only mainstem or 1-2 lateral branches remaining.

CHLOROTIC FOLIAGE (III-ob and III-D) - Tree crowns with chlorotic foliage appear in varying hues of pink or white on CIR film (Figures 1B-C). In cases of acute chlorosis, a symptom associated with the later stages of decline of American beech, Fagus grandifolia, infested by the beech scale, Cryptococcus fagi/Nectria coccinea var faginata complex, tree crowns appear white on CIR film (Mielke et al. 1984). A single acutely chlorotic tree was detected on the Chittenden site and was suspected to be an American beech in the final stages of beech bark disease.

FOLIAR INJURY (III-N) - Small areas of light reddish-brown foliage discoloration were detected on photos of the Mt. Carmel site. These were similar in appearance to a pattern of foliar injury documented on CIR photos taken in West Virginia (Mielke et al. 1984) that was attributed to leaf mining of black locust, Robinia pseudoacacia, by the locust leaf miner, Odontota dorsalis (Thunb.). Late summer skeletonizing, mining or defoliation of birch, Betula sp., foliage is common in the New York-New England area and is similar in appearance to damage caused by locust leaf miner. Several species of foliage feeding insects may be responsible, including birch casebearer, Coleophora fuscendinella (Zell.), birch skeletonizer, Buccalatrix canadensisella, Chambers or birch leaf folder, Ancylis discigerana. The latter two species were reportedly widespread in southern Vermont in 1984 (Teillon et al. 1985).

FLAGGING (III-M) - Flagging is a term used to describe the presence of individual branches with acutely chlorotic or dying foliage. The classic example of flagging is the first appearance of discolored foliage on elm, Ulmus Sp. in the early stages of infection by Dutch elm disease caused by the fungus, Ceratocystis ulmi. Flagging appears as streaks of white foliage in a magenta (healthy) or pink (chlorotic) crown on CIR film (Figure 1-D). Groups of trees expressing this symptom were detected on photos of the Chittenden site.

BRANCH DIEBACK (II-B) - Trees with varying degrees of branch dieback were detected in all of the target sites (Figure 1-E). Frequently, tree crowns with this symptom also had thin or chlorotic foliage. Sugar maples in late stages of decline only have living foliage on epicormic branches close to the mainstem (Figure 2). These trees cannot be reliably separated from recently dead trees on aerial photos at the scales compared in this evaluation.

TREE MORTALITY (I-D) - Tree mortality was the most conspicuous damage type encountered and was present on both conifers and hardwoods at the Chittenden site, which included a small rocky knob containing a stand of red spruce and balsam fir, Abies balsamea. Conifer and hardwood mortality are easily separated on aerial photos on the basis of branch patterns. In conifers, all of the branches radiate from the mainstem. The pattern on recently dead hardwoods is more complex and consists of a dendritic network of branches (Figure 1-F).

Deterioration of dead crowns is a gradual and continuing process and appears on aerial photos as a loss of fine branches (Figures 1-G and I). The remaining branches and mainstem tend to become lighter in color as the bark slips (I-A). On CIR film, older dead trees and snags tend to image as white.

Figure 2 - Sugar maple in final stages of decline near Chittenden, Vermont. Note dead top and concentration of foliage on epicormic branches near mainstem.

Color is not a reliable indicator of the age of dead trees however, because in northern hardwood forests there is often a scattering of white barked grey and white birches, B. papyrifera and B. populifolia, in the stands.

A dichtomous key, to aid in classification of the various damage types which might be encountered in a late summer inventory of hardwood decline and mortality, is shown in Table 2. Only hardwoods with branch dieback (Figure 1-E) and recently dead hardwoods (Figure 1-F) were included in the photo counts as dead or declining trees.

EFFECT OF SCALE ON PHOTO COUNTS

Precision of photo counts made at each scale by the same photo interpreter was compared using a chi-square test (Freese, 1960). Levels of precision were set at 10 and 20 percent of the 1:4000 scale photo counts. Photo counts from the 1:4000 scale data were treated as the "standard" method. Counts from the other scales were considered data from two new methods. The probability of a Type I error, detection of differences when the populations are the same, was set at 0.05. The 1:6000 scale counts were within 10 percent of the 1:4000 scale counts and the 1:8000 scale counts were within 20% of the 1:4000 scale counts when tested.

Independent photo counts on the 1:4,000 scale photos by two photo interpreters showed that each photo interpreter was capable of detecting approximately two-thirds of the simulated ground count (Table 3). Detection probabilities decreased with decreasing photo scale (Table 4).

Linear regressions of simulated ground counts on photo counts from the 1:6,000 and 1:8,000 photos showed relatively high correlations; $R^2 = .92$ and .81 respectively (Table 5). This indicates that counts of dead and declining trees at either photo scale are capable of predicting ground counts if an aerial photo/ground survey using a double sampling with regression approach (Wear et al. 1966) is used.

As photo scale increases, the relationship between photo counts and ground counts is expected to increase. A consequence of increasing photo scale, of course, is that the area coverage of each photo is reduced. Land area covered on a single 9-inch frame at scales of 1:4,000; 1:6,000; and 1:8,000 is 206.6, 465, and 826.4 acres respectively. Therefore, additional photo coverage would have to be acquired at the larger scale, at an increased acquisition cost or the inventory team would have to accept the statistical consequences of sampling a smaller land area.

GROUND DATA

Field evaluations of the Chittenden site, the site with the heaviest concentration of decline and mortality, indicated that it consisted of a mature to overmature stand of northern hardwoods. Principle species were sugar maple, yellow birch, B. alleghaniensis, and American beech with lesser amounts of white ash, F. americana, black cherry, Prunus serotina, red maple, A. rubrum, and paper birch. Trees suffering from decline and mortality occurred in distinct groups where trees of all species present on the site were affected (Figure 3).

Table 2 - Dichotomous key to aid in classification of vegetation damage types on color-IR photos in areas of Vermont affected by hardwood decline and mortality (for photos taken from August to early September).

1.	Little or no foliage present, bare branches visible	2
1a.	Foliage present in at least part of crown	5
2.	Branch pattern dendritic, color light gray or white (dead hardwood)	3
2a.	Branches radiating from a central mainstem, color light gray or white	Dead conifer
3.	Fine branches abundant, color light gray or blue-gray (white if white or gray birch)	Recent dead hardwood
3a.	Fine branches less abundant or entirely missing, color white	4
4.	Some fine branches still present	Older dead hardwood
4a.	Only mainstem or one or two large lateral branches present	Snag
5.	Foliage color red, magenta or red-brown	6
5a.	Foliage color pink, white, yellow or yellow-orange	9
6.	Crown conical or deeply lobed, foliage color normally dark red-brown or red-violet (light red-brown near sunspot)	Living conifer
6a.	Crown rounded, widespreading or multiple, foliage color red, light reddish-brown or magenta	7
7.	Foliage color light reddish-brown	Foliage injury by leaf mining or leaf skeletoning insects
7a.	Foliage color red or magenta	8
8.	Dead branches visible in crown	Hardwood with top or branch dieback
8a.	Dead branches not visible in crown	Apparently healthy hardwood
9.	Foliage color yellow or orange-yellow	10
9a.	Foliage color white or pink	12
10.	Foliage color a distinct yellow	11
10a.	Foliage color yellow-orange or orange (hardwoods only)	Hardwood with premature fall coloring
11.	Crown shape conical	Dying conifer (spruce or fir)
11a.	Crown shape rounded	Dying hardwood
12.	Foliage color pink	Slightly chlorotic hardwood
12a.	Foliage color white	Acutely chlorotic hardwood

Table 3 - Comparison of two independent counts of dead and declining trees on three central Vermont test sites at a scale of 1:4,000 - August 1984

Site	PI Count # 1 (WMC) Number	PI Count # 1 (WMC) Percent 1/	PI Count # 2 (RJM) Number	PI Count # 2 (RJM) Percent 1/	Counts - Common to both photo interpreters	Simulated 2/ Ground Count
1	87	60.7	112	77.2	67	145
2	124	50.0	172	69.4	86	248
3	309	66.2	336	71.9	222	467

1/ Expressed as a percent of the simulated ground count.

2/ Simulated ground count derived from capture/recapture method as described by Maxim et al. (1981) using two independent counts of declining and dead trees on the 1:4,000 scale photos.

Table 4 - Comparison of number and proportion of dead and declining trees counted on CIR aerial photos at three photo scales on three central Vermont test sites - August 1984.

Site	Simulated Ground Count (Number)	Photo Scale 1:4,000 Number	1:4,000 Percent	1:6,000 Number	1:6,000 Percent	1:8,000 Number	1:8,000 Percent
1	145	88	60.7	82	56.6	77	53.1
2	248	124	50.0	111	44.8	116	46.7
3	467	309	66.2	298	63.8	268	57.4
Overall	860	521	60.5	491	57.1	461	53.0

Table 5 - Comparison of linear regressions of photo counts of dead and declining hardwoods at two photo scales versus simulated ground counts - central Vermont - August 1984.

Scale	Mean X[1]	Mean Y[2]	Linear Regression Equation	R^2	F
1:6,000	10.1	17.7	$Y = 3.84 + 1.40\ X$	.92	498.1
1:8,000	10.3	17.7	$Y = 2.55 + 1.48\ X$	.81	201.9

[1] X = Photo count of dead and declining trees on a 2.5 acre cell.
[2] Y = Simulated ground count derived from capture/recapture method using two independent counts of declining and dead trees on 1:4,000 scale photos.

The Chittenden site is known to have suffered defoliation by forest tent caterpillar during the period 1978-82[4]. In addition, damage by sugar maple borer, Glycobius speciousus (Say), a trunk infesting cerambycid, was common on the boles of many sugar maples. The components of the beech bark disease complex; the beech scale and the nectria fungus were observed on many of the American beech in the stand. These observations confirm the association of a complex of causal agents with the decline syndrome.

CONCLUSIONS

The results of this work indicate the following:

1. CIR aerial photos are a viable tool for making systematic counts of symptomatic hardwoods as an intermediate sampling stage to inventory decline and mortality in northern hardwood forests.

2. A wide range of forest damage types are visible on CIR aerial photos. Some are directly related to hardwood decline and mortality while others, such as dead conifers or hardwood defoliation, are potential sources of commission error. Several damage types, such as early fall coloring of foliage or chlorosis which are the result of subtle color gradations may be difficult to classify consistently, therefore photo counts should be confined to trees with more definitive damage symptoms; branch dieback or recent mortality. Trees in the final stages of decline, with foliage present only on epicormic branches

[4] Personal communication, May 1985, H. Brenton Teillon and Barbara S. Burns, Vermont Department of Forests, Parks and Recreation.

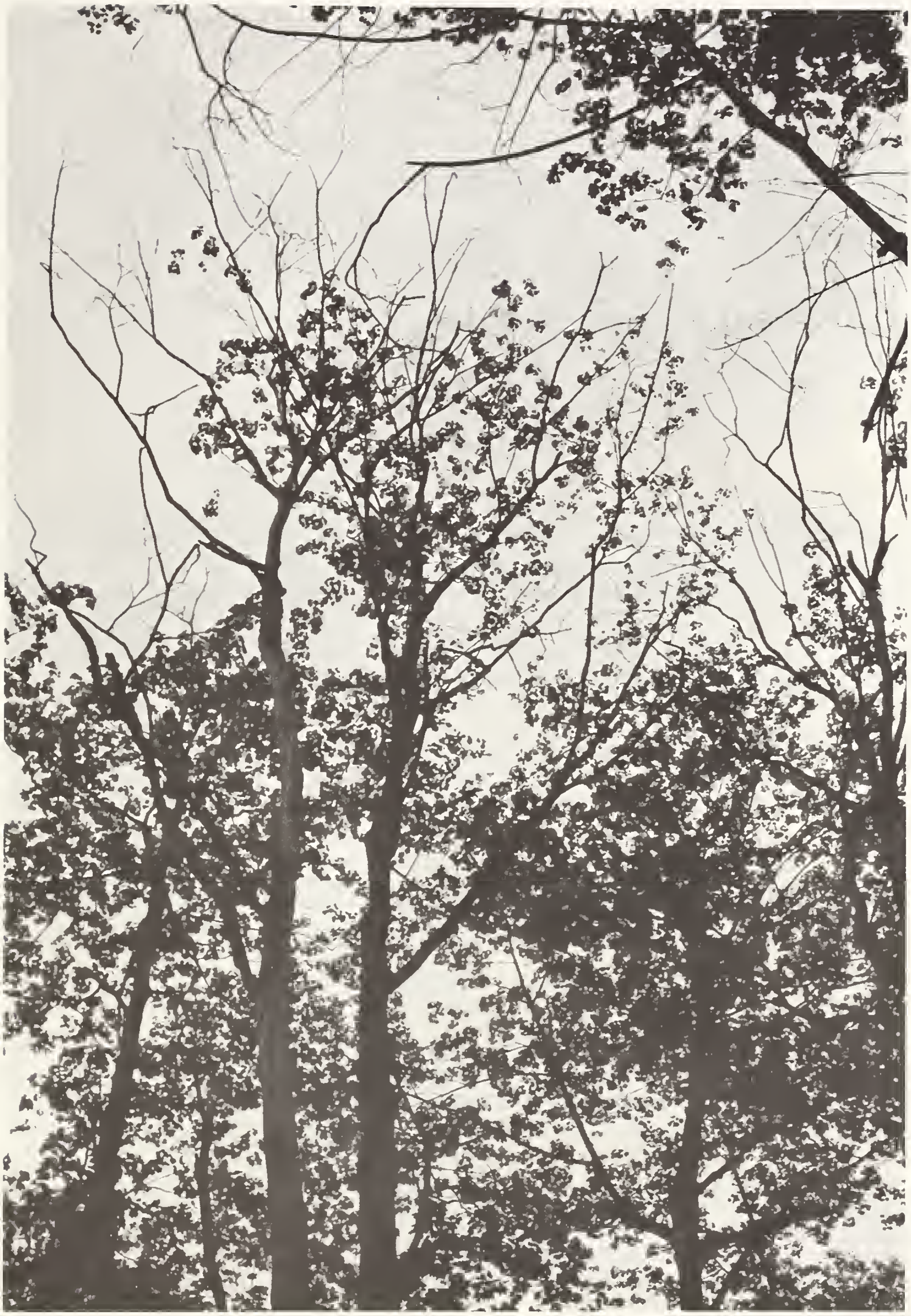

Figure 3 - Group of hardwoods with varying degrees of branch dieback near Chittenden, Vermont.

near the mainstem, may appear as recently dead trees on aerial photos. Therefore, a combined estimate of declining and dead hardwoods may be more realistic and attainable.

3. Photo counts of declining and dead hardwoods at a photo scale of 1:8,000 should provide an adequate prediction of ground conditions. Larger scale photos will provide more reliable predictions, especially of trees with early stages of branch dieback; however, as scale is decreased there is an accompanying reduction of area coverage per photo frame.

4. Areas of dieback and mortality in northern hardwood stands may involve several tree species and a variety of causal agents.

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